Biogenic Fluxes of Carbon Dioxide in and Around the Greater Toronto and Hamilton Area

Sabrina Madsen[1,*], Dien Wu[2], Lucy Hutyra[3], Ian A Smith[3], Md Abdul Halim[1], Muhammad Altaf Arain[4], Ralf M Staebler[5], Debra Wunch[1]

[1] University of Toronto, [2] California Institute of Technology, [3] Boston University, [4] McMaster University, [5] Environment and Climate Change Canada

Introduction

Motivation:

- It's difficult to differentiate between biogenic and anthropogenic CO_2.
- Vegetation is part of Canada and Toronto's plans to reach Net Zero.

Study Area: Greater Toronto and Hamilton Area (GTHA):

- Most populous region in Canada.
- Surrounded by the Greenbelt of Ontario: a region set aside for protection of croplands natural lands (Fig. 2).
- Areas of the Greenbelt were recently proposed for removal.

Background:

- Vegetation absorbs and emits CO_2 during photosynthesis (GPP) and respiration (R_{eco}), respectively.
- Net fluxes of CO_2 from vegetation: NEE = R_{eco} - GPP
- Solar Induced Fluorescence (SIF), light emitted by plants, can be used to estimate the amount of CO_2 absorbed during photosynthesis.
- Vegetation models can use relationships between observed quantities such as SIF and temperature, and biogenic fluxes of CO_2 to estimate NEE.

Methods

- Improved the spatial resolution of the SIF for Modelling Urban biogenic Fluxes (SMUrF) vegetation model [5] by using downscaled SIF from the TROPOspheric Monitoring Instrument (TROPOMI) [4] & accounted for effects of impervious surfaces on biogenic fluxes.
- Adjusted Urban Vegetation Photosynthesis and Respiration Model (UrbanVPRM) [2] to use a more in depth R_{eco} equation [1] & improved seasonality of GPP.
- Validated the models using eddy-covariance flux tower data (Fig.1).
- Estimated NEE in the Greenbelt of Ontario using SMUrF.
- Applied SMUrF and UrbanVPRM to Toronto in 2018.

Results

SMUrF and UrbanVPRM Comparison to Eddy-Covariance Flux Towers:

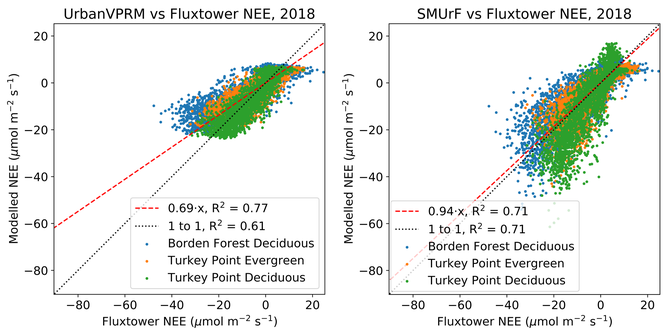

Figure 1. Net vegetation CO_2 fluxes (NEE) from the UrbanVPRM (left) and SMUrF model (right) compared to NEE measured from 3 eddy-covariance flux towers in Southern Ontario. Modifications to UrbanVPRM and SMUrF improved agreement. SMUrF agrees slightly better with flux tower data compared to UrbanVPRM.

Vegetation in the Greenbelt of Ontario absorbs 19% of the Greater Toronto and Hamilton Area's Anthropogenic Emissions

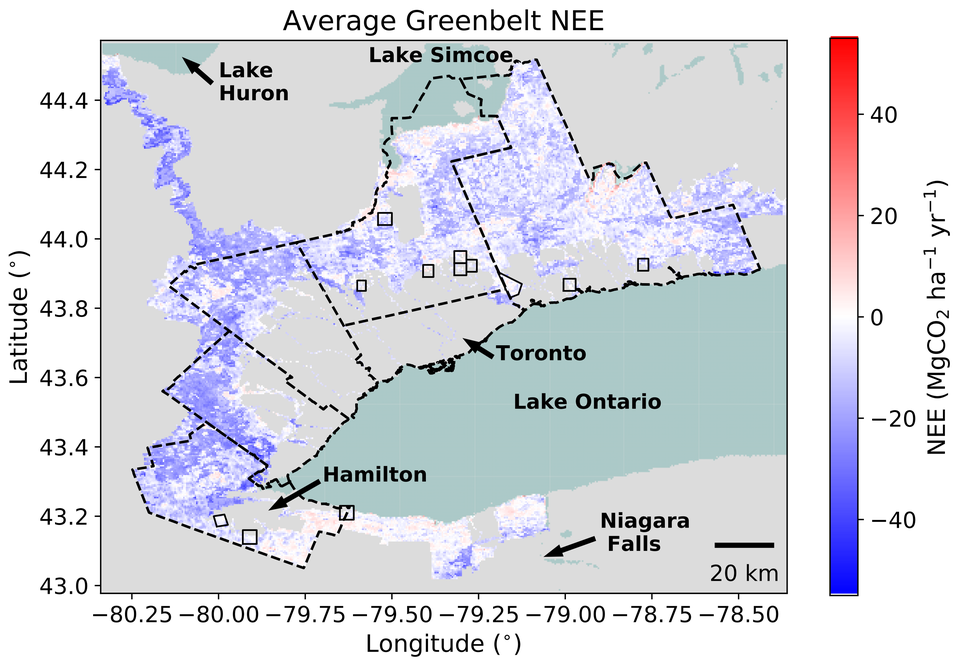

Figure 2. Net annual biogenic CO_2 fluxes from the Solar induced fluorescence for Modelling Urban biogenic Fluxes (SMUrF) model in the Greenbelt of Ontario, averaged over 2018–2020. Negative (blue) values represent a net sink, while positive (red) values represent a net release of CO_2 by vegetation. The dashed black outlines represent the boundaries of the regional municipalities in the Greater Toronto and Hamilton Area. Smaller solid black polygons represent areas proposed for removal.

Results Continued

SMUrF and UrbanVPRM in Toronto:

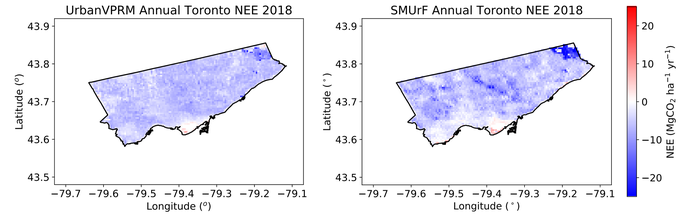

Figure 3. Annually-summed Net vegetation CO_2 fluxes (NEE) from the UrbanVPRM (left) and SMUrF (right) model In the city of Toronto, Canada in 2018. Both UrbanVPRM and SMUrF estimate that vegetation in Toronto is a sink of CO_2. UrbanVPRM shows less spatial variability and estimates vegetation is a slightly smaller sink than the SMUrF model.

Comparison of NEE and Anthropogenic Emissions:

Source of fluxes	Total Annual Fluxes
Average Greenbelt NEE:	-9.9 ± 6.4 $TgCO_2$
Average Emissions from the GTHA:	52.9 $TgCO_2$ eq.
SMUrF NEE, Toronto (2018):	-0.60 ± 0.27 $TgCO_2$
VPRM NEE, Toronto (2018):	-0.57 ± 0.28 $TgCO_2$
Emissions from Toronto (2018):	15.0 $TgCO_2$ eq.

- SMUrF estimates the Greenbelt of Ontario sequesters 19% of the GTHA's anthropogenic CO_2 eq. emissions [3].
- Both UrbanVPRM and SMUrF estimate Toronto's vegetation sequestered approximately 4% of Toronto's anthropogenic CO_2 eq. emissions in 2018 [3].

References

[1] Sharon M. Gourdji, Anna Karion, Israel Lopez-Coto, Subhomoy Ghosh, Kimberly L. Mueller, Yu Zhou, Christopher A. Williams, Ian T. Baker, Katharine D. Haynes, and James R. Whetstone. A modified Vegetation Photosynthesis and Respiration Model (VPRM) for the Eastern USA and Canada, evaluated with comparison to atmospheric observations and other biospheric models. *Journal of Geophysical Research: Biogeosciences*, 127(1):e2021JG006290, 2022.

[2] Brady S. Hardiman, Jonathan A. Wang, Lucy R. Hutyra, Conor K. Gately, Jackie M. Getson, and Mark A. Friedl. Accounting for urban biogenic fluxes in regional carbon budgets. *Science of The Total Environment*, 592:366–372, 2017.

[3] M. Shekarrizfard and J. Sotes. Reality check: Carbon emissions inventory for the Greater Toronto and Hamilton Area 2018. Technical report, The Atmospheric Fund, 2021.

[4] A. J. Turner, P. Köhler, T. S. Magney, C. Frankenberg, I. Fung, and R. C. Cohen. A double peak in the seasonality of California's photosynthesis as observed from space. *Biogeosciences*, 17(2):405–422, 2020.

[5] D. Wu, J. C. Lin, H. F. Duarte, V. Yadav, N. C. Parazoo, T. Oda, and E. A. Kort. A model for urban biogenic CO_2 fluxes: Solar-Induced Fluorescence for Modeling Urban biogenic Fluxes (SMUrF v1). *Geoscientific Model Development*, 14(6):3633–3661, 2021.

Funding

We acknowledge the support of the Natural Sciences and Engineering Research Council of Canada (NSERC) and Climate Positive Energy.

*smadsen@physics.utoronto.ca